HUMAN FACTORS ANALYSIS OF NAVAL AVIATION MAINTENANCE RELATED MISHAPS

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ABSTRACT
Naval Aviation has redoubled its long-standing efforts to eliminate mishaps, especially those linked to human error. The focus was expanded not only to cover aircrew error, but maintainer error as well. To examine maintainer error, the Naval Safety Center's Human Factors Analysis and Classification System (HFACS) was adapted to analyze reportable Naval Aviation maintenance related mishaps (MRMs). A total of 470 MRMs for Fiscal Years 90-97 were analyzed. The HFACS Maintenance Extension effectively profiled the nature of maintenance errors and depicted the latent supervisory, working, and maintainer conditions that "set the stage" for subsequent maintainer acts that were the proximate factors leading to a MRM. The profile and general findings held true for both major MRMs and less severe, reportable MRMs.

INTRODUCTION

Marx (1998) in a review of investigation and analysis systems for aircraft maintenance error states that human error is "under-served" by most traditional event investigation methods. He finds that they effectively end with identifying a human error without any effort to determine why it occurred. Many researchers (Adams & Hartwell, 1977; Boyle, 1980; Edwards, 1981; Benner, 1982; Pimble & O'Toole, 1982; Andersson & Lagerloff, 1983) have observed this same problem and attribute it to several factors: 1) the reporting criteria; 2) investigator biases; 3) the report's scope, depth, and quality; 4) reporting process(es) and system design; and 5) database construction. Marx reflects that only through human factors investigation and reporting "industry can now begin to understand why people make certain mistakes."

Harle (1994) asserts that "accident prevention is critically linked to the adequacy of the investigation of human factors." However, the same problems can plague such a process as traditional ones if not properly designed, implemented, and supported. Zotov (1996) reflecting on International Civil Aviation Organization (ICAO) reports involving human factors states that they "frequently generated more heat than light." Further, Bruggin (1996) finds the reactive use of human factors accident data fails to "exploit the preventive potential of the human element that safeguards the system."

Even though there is general agreement in the aviation industry that human factors based investigation methods are superior, they are not widely used. Marx (1998) cites that of 92 carriers trained to use the Maintenance Error Decision Aid (MEDA), only six were in the United States. He notes that this was in spite of the fact that 15% of air carrier mishaps are attributed to maintenance error at an annual cost of over a billion dollars. Some of the reasons cited include: their general tendency to place blame; not transcending the proximate causes and digging for underlying ones; and over emphasizing static factors (who, what, when, etc.).

A conceptual framework for understanding human error that has gained fairly wide acceptance across the government, military, and commercial sectors is the one established by Reason's model of human error causation (1980; 1995). It shows that an unsafe individual act is not only an accident-generating agent, but that organizational processes and task/ environment conditions "set the stage" for their occurrence. Marx (1998) laments that despite its acceptance, the Reason model does not provide for identifying precursors to accidents.

HFACS - MAINTENANCE EXTENSION

The Human Factors Analysis and Classification System (HFACS) was developed by the Naval Safety Center to analyze human errors contributing to Naval Aviation mishaps (Shappell, 1997; Weigmann & Shappell, 1997). It integrates features of Heinrich's "Domino Theory"(Bird, 1974; Heinrich, Petersen, & Roos, 1980) and Edward's "SHEL Model" (Edwards, 1972; Hawkins, 1993) as well as Reason's "Human Error" model (Reason, 1990; 1991) to fully depict factors that are precursors to accidents. The latent factors or "conditions" set the stage for the active factors or "failures" that precede a mishap. These classifications can target areas for intervention.

The HFACS taxonomy was adapted to classify factors that lead to Maintenance Related Mishaps (MRMs) (Schmidt, Schmorrow, & Hardee, 1998). The "Maintenance Extension" consists of Supervisory, Maintainer, and Working Conditions, and Maintainer Acts. In HFACS-ME (see Figure 1), "conditions" are latent and can impact maintainer performance, contributing to an active failure in the form of an unsafe Maintainer Act. Such failures may directly lead to a mishap or injury, for example an operator runs a forklift into an aircraft, damaging it; or can lead to a latent Maintenance Condition, that aircrew would handle on take-off, in-flight, or on landing, for example, an improperly rigged landing gear that collapses on landing or an over-torqued hydraulics line that fails in flight causing a fire. Supervisory Conditions tied to poor design for maintainability, inadequate maintenance procedures, or improper standard maintenance operations can lead directly to a Maintenance Condition. Finally, latent Supervisory, Maintainer, and Working Conditions can also interact with one another.

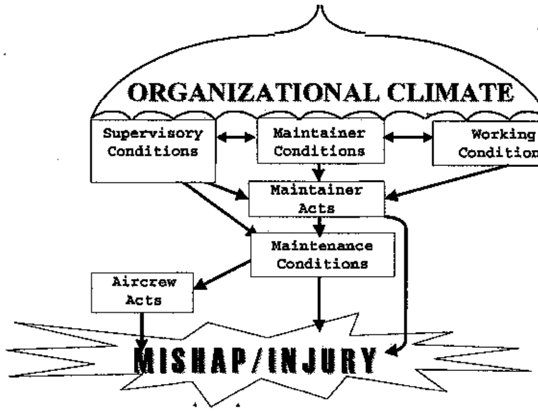

Figure 1. HFACS - Maintenance Extension

This section provides a brief illustration of the HFACS-ME taxonomy. The three orders of maintenance error: first, second, and third reflect a decomposition of the error types from a molar to a micro perspective (see Table 1).

Table 1. HFACS-ME Taxonomy

1st Order	2nd Order	3rd Order
Supervisory Conditions	Unforeseen	Hazardous Operations Inadequate Documentation Inadequate Design
	Squadron	Inadequate Supervision Inappropriate Operations Failed to Correct Problem Supervisory Violation
Maintainer Conditions	Medical	Adverse Mental State Adverse Physical State Physical/Mental Limit
	Crew Coordination	Communication Assertiveness Adaptability/Flexibility
	Readiness	Preparation/Training Qualification/Certification Violation
Working Conditions	Environment	Lighting/Light Exposure/Weather Environmental Hazard
	Equipment	Damaged/Broken Unavailable Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention/Memory Rule/Knowledge Skill/Proficiency
	Violation	Routine Infraction Exceptional

Supervisory Conditions that lead to an active failure consists of both unforeseen organizational and squadron level errors:
Examples of unforeseen organizational conditions-
• An engine change is performed despite a high sea state and it falls off a stand (Hazardous Operation)
• A manual omits a step calling for an o-ring that leads to a fuel leak (Inadequate Documentation)
• Poor component layout prohibited direct viewing maintenance being per-formed (Inadequate Design)
Examples of squadron supervisory conditions-
• A supervisor does not ensure that personnel wear required protective gear (Inadequate Supervision)
• A supervisor directs a nonstandard procedure with -out considering risks (Inappropriate Operations)
• A supervisor neglects to correct cutting corners on in performing a routine task (Uncorrected Problem)
• A supervisor willfully orders personnel to wash an aircraft without training (Supervisory Violation)

Maintainer Conditions that lead to an active failure are medical, crew coordination, and readiness:
Examples of maintainer medical conditions-
• A maintainer has a marital problem and cannot focus on a maintenance action (Mental State)
• A maintainer works for 20 hours straight and suffers from fatigue (Physical State)
• A short maintainer can not visually inspect an aircraft component (Physical Limitation)
Examples of maintainer crew coordination conditions-
• A maintainer leads a taxiing aircraft into another due to improper hand signals (Communication)
• A maintainer signs off an inspection due to perceived pressure (Assertiveness)
• A maintainer downplays a discrepancy to meet the flight schedule (Adaptability)
Examples of maintainer readiness conditions-
• A maintainer working on an aircraft skipped a requisite on the job training evolution (Training)
• A maintainer engages in a procedure they are not been qualified to perform (Certification)
• A maintainer is intoxicated on the job (Violation)

Working Conditions that can contribute to an active failure are environment, equipment, and workspace:
Examples of environment working conditions-
• A maintainer working at night on the flight line does not see a tool left behind (Light)
• A maintainer securing an aircraft in a driving rain fails to properly attach the chains (Weather)
• A maintainer working on a pitching deck falls from an aircraft (Environmental Hazard)
Examples of equipment working conditions-
A maintainer uses the only test set that is faulty (Damaged)
• A maintainer starts working on a landing gear without a jack because all are in use (Unavailable)
• A maintainer uses an old manual because a CD-ROM is not available to review the new one (Dated)
Examples of workspace working conditions-
• A maintainer working in a hangar bay cannot properly position the maintenance stand (Confining)

• A maintainer is spotting an aircraft with his view obscured by catapult steam (Obstructed)
• A maintainer is unable to perform a corrosion inspection that is beyond his reach (Inaccessible)

Maintainer Acts are active failures which directly or indirectly cause mishaps, or lead to a Latent Maintenance Condition that an aircrew would have to respond to during a given phase of flight, they include errors and violations:
Examples of errors in maintainer acts include-
• A maintainer misses a hand signal and backs a tow tractor into an aircraft (Attention)
• A maintainer inflates an aircraft tire using a pressure required by a different aircraft (Rule)
• A maintainer roughly handles a delicate engine valve causing damage (Skill)
Examples of violations in maintainer acts-
• A maintainer engages in practices, condoned by management, that bend the rules (Routine)
• A maintainer strays from accepted procedures to save time, bending a rule (Infraction)
• A maintainer willfully breaks standing rules disregarding the consequences (Exceptional)

METHODS

Database

The Naval Safety Center's Information Management System was queried to obtain all MRMs for FYs 90-97. A total of 470 MRM cases were considered in this analysis.

Judges

Two Naval Officers, well versed in the HFACS-ME taxonomy and experienced in maintenance operations reviewed the causal factors present in the MRM cases.

Procedure

The two judges independently reviewed each MRM case, and its respective HFACS-ME codes were entered into a spreadsheet for subsequent tabulation and analysis. Each MRM causal factor was given only one HFACS-ME code, and codes were only assigned to issues clearly identified as having had contributed to the mishap. Cohen's kappa was calculated as a measure of rater agreement and inter-rater reliability. A kappa of .75 was obtained, indicating an overall "excellent" agreement level between the two judges. Codes, which were disputed, were discussed and resolved on the spot or after conferring with a third party.

Analysis

Each HFACS-ME category frequency counts were totaled and respective percentages were calculated for subsequent comparison.

HFACS-ME ANALYSIS OF FYs 90-97 MRMs

During FYs 90-97 there were 63 Class A MRMs (those involving the loss of an aircraft or a faulty), of which 50 were Flight, 0 were Flight Related, and 13 were Aircraft Ground. The original analysis of Class A MRMs conducted by Schmidt, Schmorrow, and Hardee (1998) had two Navy Maintenance Officers and Chief Petty Officers use the HFACS-ME to classify the human factors causes reported in these mishap cases. A profile for the HFACS-ME taxonomy results was charted for the Class A MRMs (see Figure 2). The following is a breakout of the errors in found Naval Aviation Class A MRMs for FY 90-97:
<u>Supervisory Conditions</u>- 67% of Class A MRMs had squadron conditions, whereas 21% had an unforeseen one (not shown).
<u>Maintainer Conditions</u>- 21% of all Class A MRMs had medical, crew coordination (16%), or readiness condition.
<u>Working Conditions</u>- 3% of all A MRMs had an environment, equipment, or workspace conditions.
<u>Maintainer Acts</u>- 75% of all Class A MRMs had a maintainer error, whereas 40% had a violation.

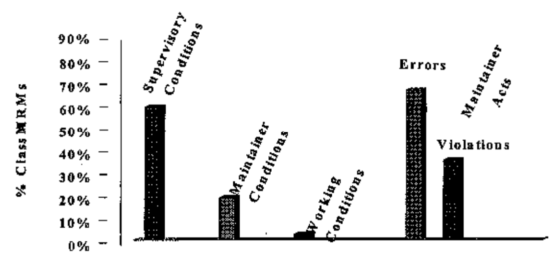

Figure 2. HFACS-ME Profile Of Class A MRMs

During FYs 90-97 there were 407 other MRMs of lesser severity (Class B/C) in Naval Aviation (see Table 2). The majority of these MRMs (265, 65%) involve ground and fight line activities. Consequently, the previous profile may only hold for major MRMs. It can then be contended that the interventions for major MRMs involving maintenance activities (i.e., engine repair) may not work for less severe MRMs involving fight line activities (i.e., aircraft towing.)

Table 2 FYs 90-97 Naval Aviation MRMs

	Flight	Flight Related	Aircraft Ground	Total
Class A	50	0	13	63
Class B	17	6	34	57
Class C	90	29	231	350
Total	157	35	278	470

Two judges applied the HFACS-ME taxonomy to the Class A, B, and C MRMs. Percents for each error type were determined for major and minor mishaps, and resultes were charted (see Figure 3).

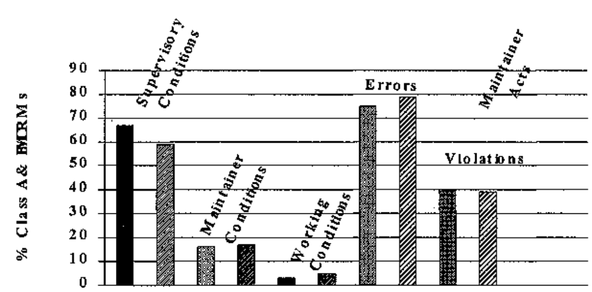

Figure 3. HFACS-ME Profile Of Class A vs B/C MRMs

The following is a breakout of the errors in found Naval Aviation Class A, B, and C MRMs for FY 90-97:

squadron condition (compared to A's at 67%), 22% of Class B/C had unforeseen condition (compared to A's at 21%).
Maintainer Conditions- 17% of Class B/C MRMs had a crew coordination condition (compared to A's at 16%).
Working Conditions- 5% of Class B/C MRMs had an environment, equipment, space condition (compared to A's at 3%).
Maintainer Acts- 79% of Class B/C MRMs had a maintainer error (compared to A's at 75%); 39% of Class B/C MRMs had a violation (compared to A's at 40%).

The error profile for both major and less severe MRMs is comparable, despite the varied composition of primary types of operations involved. The average number of MRM causal factors reported for each Class B/C case (2.35 per MRM) was somewhat less than for the Class A cases (2.52 per MRM). This is primarily tied to minor mishaps not receiving the same attention in the investigation process as major ones, however it was not noted to be significantly different.

CONCLUSIONS

The HFACS Maintenance Extension was effective in capturing the nature of and relationships among latent conditions and active failures present in Class A MRMs as well as less severe Class B/C MRMs. The insights gained provide a solid perspective for the development of potential intervention strategies. The major mishaps analyzed were primarily Flight Mishaps, meaning that many imposed in-flight Maintenance Conditions on aircrew, where as most of the less severe mishaps occurred on the ground and directly led to a Mishap or Injury. Potentially then interventions that are selectively targeted at similar issues such as supervision, crew coordination, and procedural violations can be used to address problem leading to bot major and minor mishaps, and those involving pure maintenance, flight line activities, and ground operations.

Clearly, supervisory, maintainer, and working latent conditions are present that can impact maintainers in the performance of their jobs. However, many maintainer and working conditions are not recorded due to the reporting system in place, perceptions of accident causation, or organizational climate issues. Specifically, inadequate supervision of maintenance evolutions, not ensuring personnel are trained and/or qualified, not enforcing rules, and poor communication characterize most supervisory conditions. Poor pass-down, coordination, and communication; non-use or lack of publications, policies, and procedures; and fatigue comprise most maintainer conditions. Finally, most maintainer errors reflect a lack of training, experience, and skill, whereas maintainer violations consist of routine non-compliance with procedures and infractions, bending the rules to meet mission requirements and the flight schedule. These are the general areas that should be initially targeted for intervention.

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Note. The opinons expressed are those of the authors and do not represent those of the Department of Defense, Department of the Navy, or the Naval Postgraduate School.